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THE ORIGINS OF MICROTEXTURE IN DUPLEX Ti ALLOYS (PREPRINT)

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Metals Branch
Metals, Ceramics, and NDE Division

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14. ABSTRACT

A previously developed methodology was used to transform electron backscatter diffraction (EBSD) data for the primary and secondary alpha phases of Ti-6Al-2Sn-4Zr-6Mo (Ti-6246) to the prior beta phase. The results established that the observed microtexture in duplex alloys is a direct result of the prior beta grain orientations, and variant selection. In addition, for a homogeneous duplex microstructures, all of the secondary alpha phase and the majority of the primary alpha grains retain crystallographic coherency, according to the Burgers Relationship, with the surrounding beta-phase matrix which comprise prior beta grains. This investigation establishes that this technique to recover the prior beta grain orientations is applicable to duplex alpha/beta titanium microstructures. The crystallographic coherency of the primary and secondary alpha phase with the prior beta grain coupled with variant selection then leads to the localized microtexture observed in a wide variety of Ti alloys.

15. SUBJECT TERMS

duplex titanium alloy, titanium microstructure, Ti alloy, electron backscatter diffraction, beta grain orientation, variant selection

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The Origins of Microtexture in Duplex Ti Alloys

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Abstract

A previously developed methodology was used to transform electron backscatter diffraction (EBSD) data for the primary and secondary alpha phases of Ti-6Al-2Sn-4Zr-6Mo (Ti-6246) to the prior beta phase. The results established that the observed microtexture in duplex alloys is a direct result of the prior beta grain orientations, and variant selection. In addition, for a homogeneous duplex microstructure, all of the secondary alpha phase and the majority of the primary alpha grains retain crystallographic coherency, according to the Burgers Relationship, with the surrounding beta-phase matrix which comprise prior beta grains. This investigation establishes that this technique to recover the prior beta grain orientations is applicable to duplex α/β titanium microstructures. The crystallographic coherency of the primary and secondary alpha phase with the prior beta grain coupled with variant selection then leads to the localized microtexture observed in a wide variety of Ti alloys.

Introduction

The study of microtexture in duplex titanium alloys with a microstructure that consists of equiaxed (primary) and platelet (secondary) alpha phase that is surrounded by a thin layer of beta phase at ambient temperatures is complicated by several factors. First, in order to examine if there exists a correlation in the crystallographic orientation of the alpha phase constituents (primary and secondary alpha) with that of the beta phase, high resolution EBSD patterns are required to collect a statistically representative number of data from each phase. Second, in some alloys, such as Ti-6Al-4V, where the volume fraction of retained beta phase at ambient temperatures is very low, it is even more difficult to measure the crystallographic orientation of the beta phase.

From a mechanical perspective, microtexture is an artifact of thermomechanical processing that can have a deleterious effect on the fatigue properties of titanium alloys. Recent work examining the role of crystallographic orientation of the primary alpha phase on fatigue behavior has shown that primary alpha oriented suitably for basal <a> slip serves as the fatigue crack initiation sites [1]. Invariably, the microstructural volume surrounding the fatigue crack initiation site was found to be strongly textured for basal and prism slip. Hence from a fatigue life prediction perspective, tools that aid in the understanding of how microtextures develop and the ability to predict crystallographic orientation are essential for the development of life prediction models that incorporate crystallographic orientation into a modeling framework.

The objective of the present work was to demonstrate that a previously developed Monte Carlo methodology [2-4] for transforming alpha-phase EBSD data from colony microstructures into the beta phase was also applicable for the analysis of an α + β titanium alloy with a duplex microstructure. The results were also used to determine if there exists a crystallographic relationship between the primary alpha phase and the surrounding beta phase.

Background

In titanium alloys, at moderate cooling rates from the beta transus temperature a solid state phase transformation occurs from a body-centered-cubic (bcc) to hexagonal-closed-packed (hcp) that follows what is know as the Burgers orientation relationship,

$$\begin{gathered}\{110\}_{\beta} // (0001)_{\alpha} \\ <111>_{\beta} // [2\bar{1}\bar{1}0]_{\alpha}\end{gathered} \tag{1}$$

in which there are twelve distinct possible variants that can form from a single orientation of a prior beta-phase grain. Because of the long sequence of thermomechanical processing steps that are required to produce a billet or sheet with a duplex microstructure from an ingot with an initial colony microstucture, it has been surmised in the past that the crystallographic orientation of the primary alpha phase did not likely retain any rigorous crystallographic coherency, via the Burger orientation relationship, with that of the prior beta phase. This hypothesis was based upon the fact that in order to produce a duplex microstructure from a colony microstructure severe thermomechanical working of the material in the alpha/beta phase field in conjunction with static and dynamic globularization processes are required to produce the equiaxed primary alpha grains that are observed in duplex microstructures. In contrast, the crystallographic orientation of the secondary-alpha phase has been shown to follow the Burgers orientation relationship via the correlations observed in the beta phase pole figures and those obtained for the secondary alpha phase [5].

Because the previously developed Monte Carlo methodology to transform EBSD data from the alpha phase into the beta phase [2-4], relies only upon the fact that the alpha phase EBSD data that is input into the software is related to one another via the Burgers orientation relation, it is ideally suited to examine EBSD data from a duplex microstructure in an automated fashion regardless of whether there exists crystallographic coherence of the primary-alpha phase with the surrounding beta phase.

Experiment

Ti-6Al-2Sn-4Zr-6Mo with a duplex structure (Fig. 1(a)) with an average primary alpha grain size of 4 μm and a volume fraction of 27 ± 3% was investigated in this study. The secondary alpha phase volume fraction was determined to be approximately 35% while the remaining 35% was found to be a mixture of beta phase and alpha precipitates (Fig. 1(b)). The presence of precipitates within the beta phase made it difficult to accurately determine the volume fraction of the beta phase, however, the beta phase volume fraction was sufficient to allow for direct measurement of the crystallographic orientations of the beta phase from EBSD measurements.

Specimens for EBSD analysis were prepared by both vibratory polishing and electropolishing. The electropolished surfaces generally yielded the sharpest Kikuchi patterns, but vibratory polished surfaces still allowed for the collection of reliable EBSD data. EBSD maps were collected with a resolution ranging from 0.3 to 0.5 μm step size. In the case of the largest scan, shown in *Figure 2* there are 170 high resolution scans in

17 columns of 10 rows covering an area approximately 1.7 x 1.5 mm. Due to computational limitations, the resolution of these scans was reduced by 66%, yielding an effective resolution of 1.5 μm and processing was completed individually on each of the ten rows. Subsequently, these scans were cleaned using TSL OIM Analysis software and then their resolution further decreased by a factor of 25 so that each of the 10 strips could be processed with the available computer resources. The data was cleaned by setting the euler angle within each grain the same, and filling in each data point with a confidence index less than 0.1 with surrounding data with a good confidence index.

In the results presented in Figure 4, a composite of four high resolution scans (collected at a step size of 0.1 μm), that were cleaned using the algorithms available in the TSL software package, are shown. The cleanup routine was identical to the routin performed on the data set shown in Figure 3. The data resolution was then decreased by a factor of 25 so that they could be run with the available computer resources.

Results and Discussion

Microtexture - prior-β phase relationship

The role of the prior-β phase in producing the microtexture in α+β alloys is illustrated by two representative specimens with a homogeneous duplex microstructure, shown in Figs. 2 and 3. Composite alpha-phase EBSD scans (Fig. 2(a), and 3(a)) revealed the presence of several regions of microtexture where the surrounding crystallographic orientations of the primary and secondary alpha phases were similar. Measured EBSD data from the corresponding areas for the beta phase (Fig. 2(b),and 3(b)) clearly showed that these areas of similar crystallographic orientation in the primary and secondary alpha phase were related to the crystallographic orientation of the surrounding beta matrix and delimited by the underlying beta grain boundaries. A comparison of the measured beta phase EBSD data (Fig. 2(b) and 3(b)) with that which was mathematically transformed from the primary and secondary alpha phase EBSD data (Fig. 2(c), and 3(c)), revealed that both the crystallographic orientation of the underlying beta matrix and their boundaries could be obtained with the technique described in references 2-4. Hence for alloys, where measurement of the beta phase is very difficult, such as Ti-6Al-4V, low resolution EBSD scans in conjunction with previously developed software [2-4] can be used to extract the texture of the underlying beta phase in a duplex microstructure. Moreover, the results obtained clearly show that in a homogenous duplex microstructure, the grain size of the underlying beta matrix is very large in comparison to the size of the primary and secondary alpha phase features. These, relatively large similarly oriented beta regions in conjunction with variant selection during the beta to alpha phase transformation can be considered to have produced the observed microtexture in the Ti-6246 alloy.

Primary-alpha - beta crystallographic relationship

A high resolution EBSD scan of an individual region of "microtexture" (Fig 4a) reveals that the volume fraction of the primary alpha phase constitutes approximately 30% of the microstructure with the remaining alpha phase being comprised of secondary alpha. Mathematical transformation of the duplex microstructure into its prior beta grain (Fig 4b) reveals that the majority of the primary alpha grains remain crystallographically coherent to the prior beta grain orientation via the Burgers relationship, as is evident from the fact that these grains can be transformed to the same crystallographic orientation of a prior beta grain as the secondary alpha laths. The remaining portion of the primary alpha grains which cannot be transformed to the crystallographic orientation of the prior beta grain are thereby labeled as having lost coherency with their prior beta grains.

Examination of larger mathematically transformed regions consisting of several prior beta grains that have been transformed back to its prior beta phase (Fig. 2(c) and 3(c)) also demonstrate that the majority of all primary alpha grains in these regions retain crystallographic coherency with their prior beta grain matrix. This is an unexpected result in that it has long been believed that during the static and dynamic spherodization of a colony alpha microstructure to produce a duplex microstructure, the thermomechanical processing required to initiate the spherodization process and subsequent thermomechanical steps eliminate this coherency. The present results indicate that despite having undergone speriodization processes, both static and dynamic, the crystallographic coherency is retained in majority of the primary alpha grains. A possible explanation for this observation is that the portion of primary alpha phase that has lost coherency with the prior-beta grain, constitutes the volume fraction of primary alpha that has recrystallized during the dynamic or static spherodization process of the colony alpha microstructure.

Conclusion

The development of microtexture in a duplex microstructure is a direct result of the prior beta grain boundaries, and variant selection. The results established that, in a homogeneous duplex microstructure, all of the secondary alpha phase and the majority of the primary alpha grains retain crystallographic coherency, according to the Burgers relationship, with their prior beta grain. This crystallographic coherency with the prior beta grain coupled with variant selection in the individual prior beta grains then leads to the localized microtexture observed in a wide variety of Ti alloys.

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[3] "An Automated Method to Determine the Orientation of the High Temperature Beta Phase From Measured EBSD Data for the Low Temperature-Alpha Phase in Ti-6Al-4V", M.G. Glavicic, P.A. Kobryn, T.R. Bieler and S. L. Semiatin, Mat. Sci. Eng. A351, 258-264 (2003)

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[5] "A Method to Determine the Texture of the Secondary Alpha Texture in Ti-6Al-4V Duplex Microstructures" M.G. Glavicic, J.D. Miller, and S.L. Semiatin, Scripta Mater. 54, 281-286 (2006)

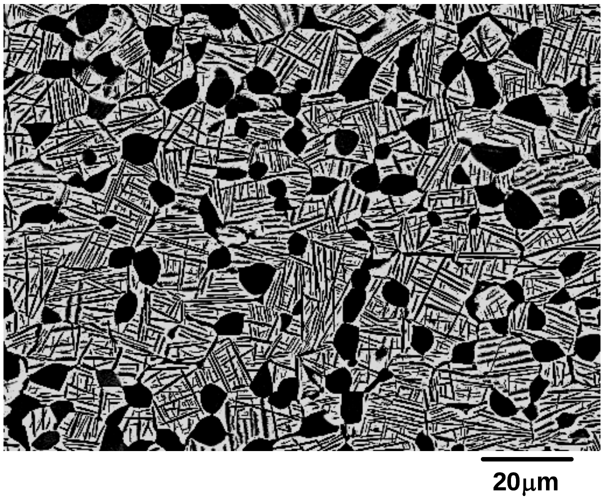
Figure Captions

Fig. 1 Electron backscatter image of Ti-6246 duplex microstructure examined; (a) primary equiaxed alpha and secondary platelet alpha structure, and (b) alpha precipitates in the β-phase matrix.

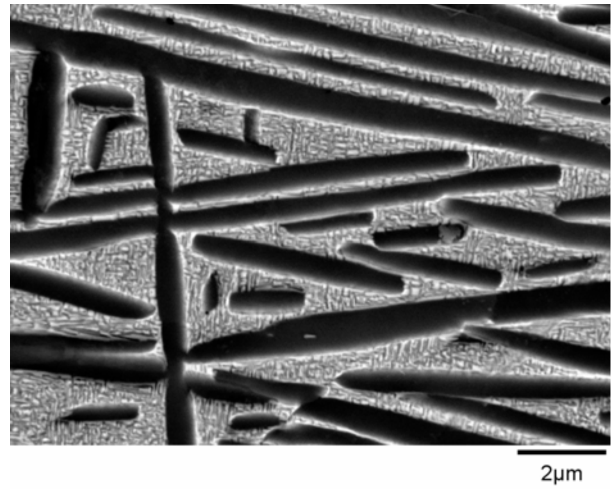
Fig. 2 EBSD maps from a region in a Ti-6246 specimen; (a) measured primary and secondary alpha phase, (b) measured beta phase, and (c) computed beta phase.

Fig. 3 EBSD maps from a region in a second Ti-6246 specimen; (a) measured primary and secondary alpha phase, (b) measured beta phase, and (c) computed beta phase.

Fig. 4 High resolution EBSD map of microtexture region in Ti-6246 duplex microstructure; (a) primary and secondary alpha phase, and (b) computed beta phase.



(a)



(b)

Figure 1

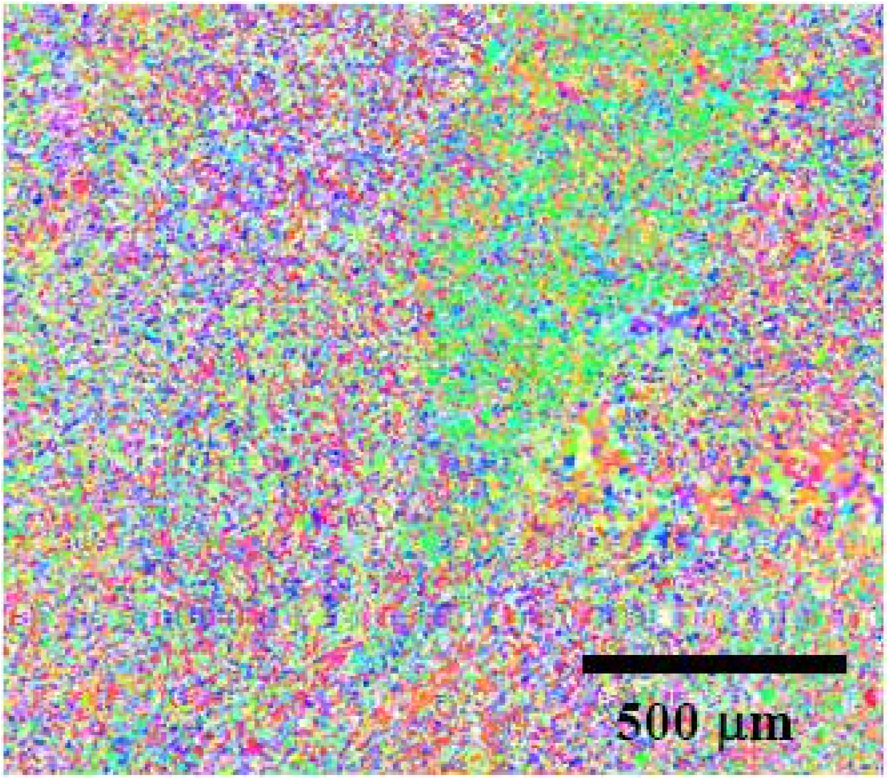
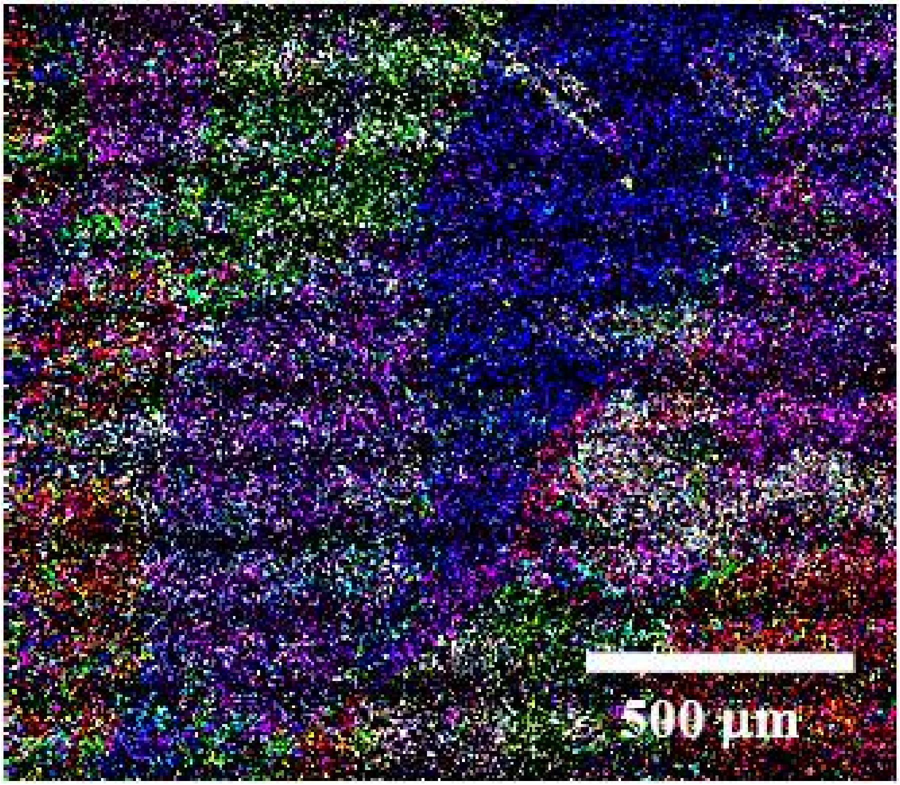


Figure 2a:



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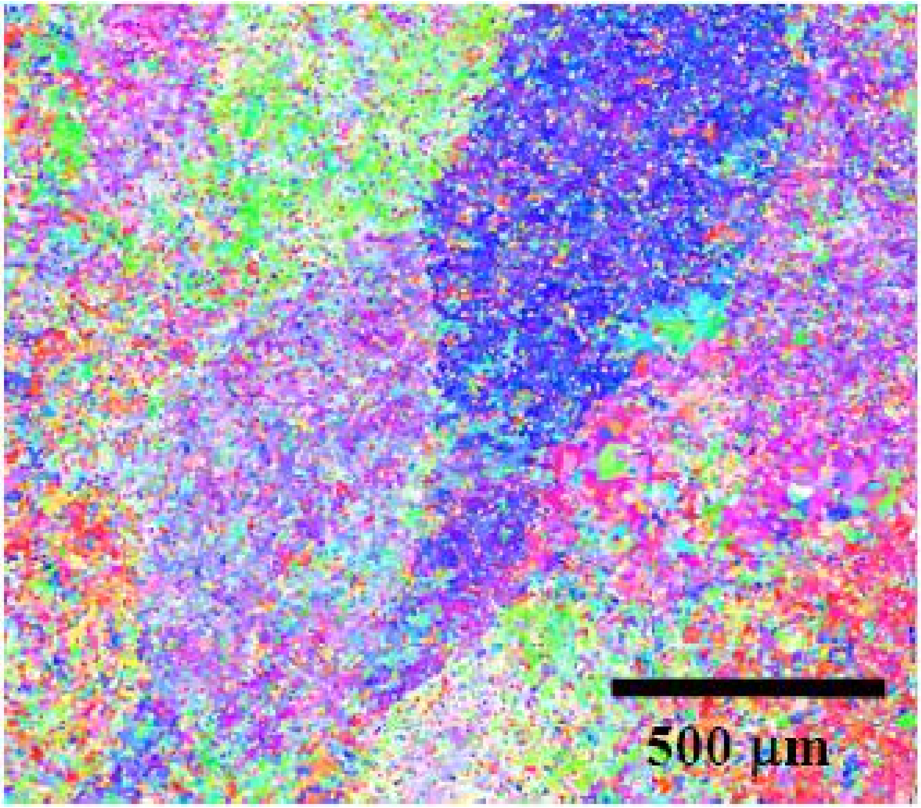


Figure 2c:

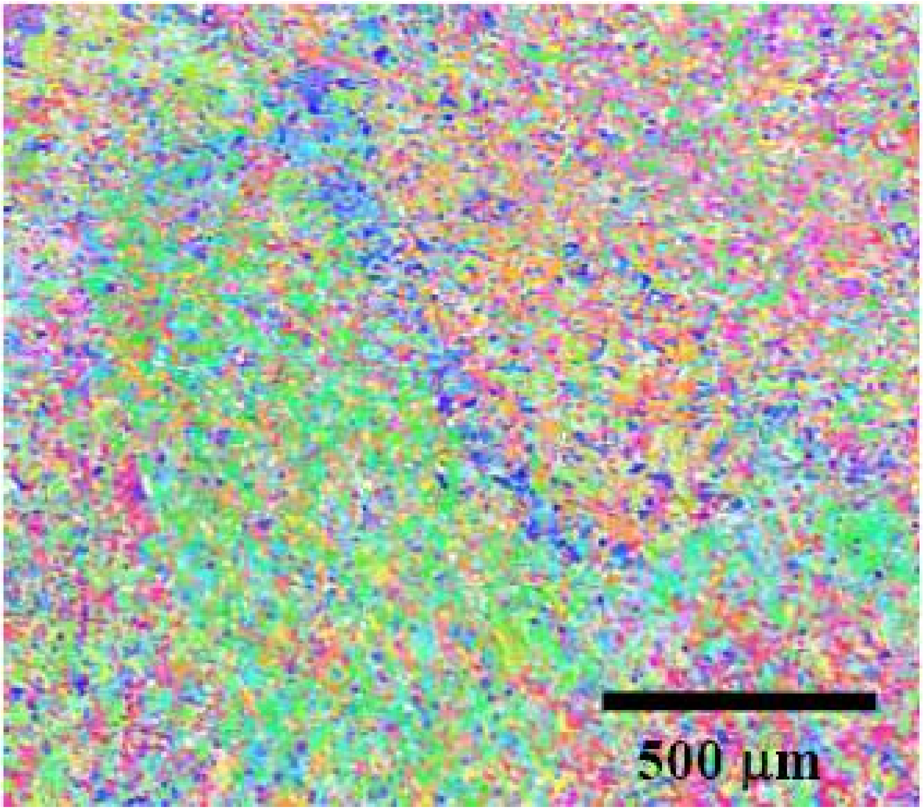


Figure 3a

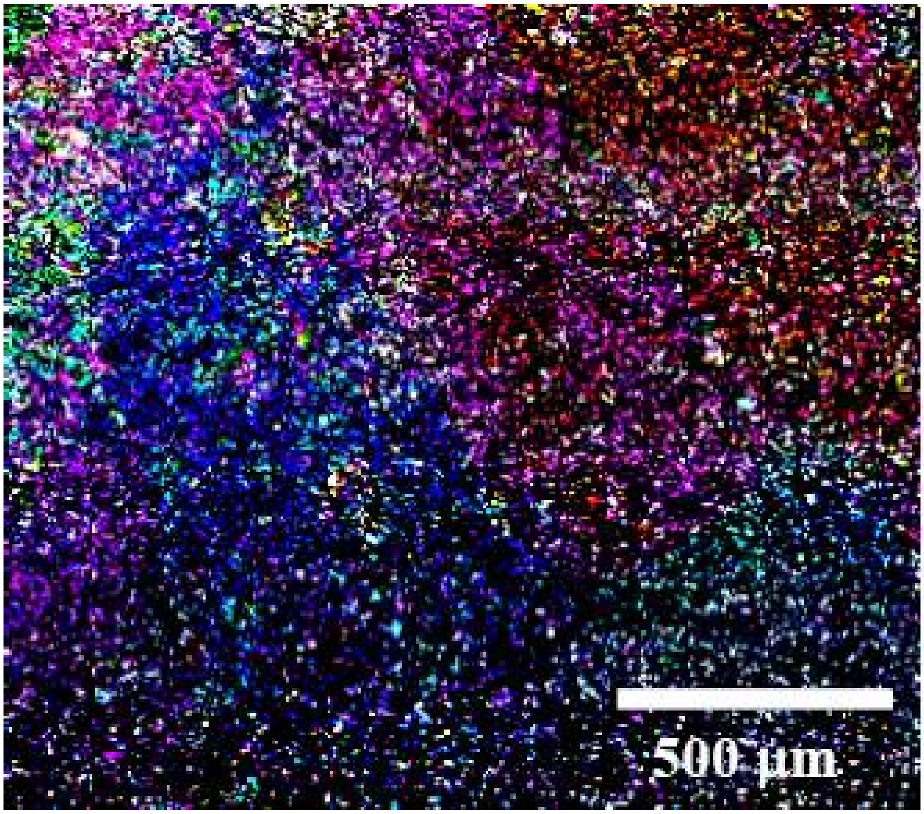


Figure 3b:

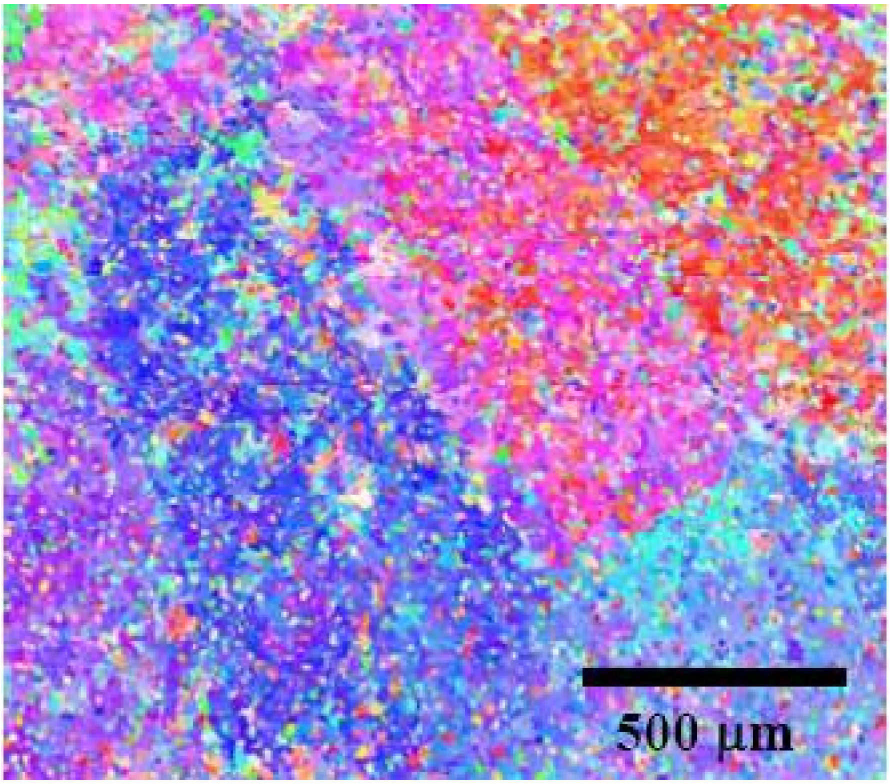
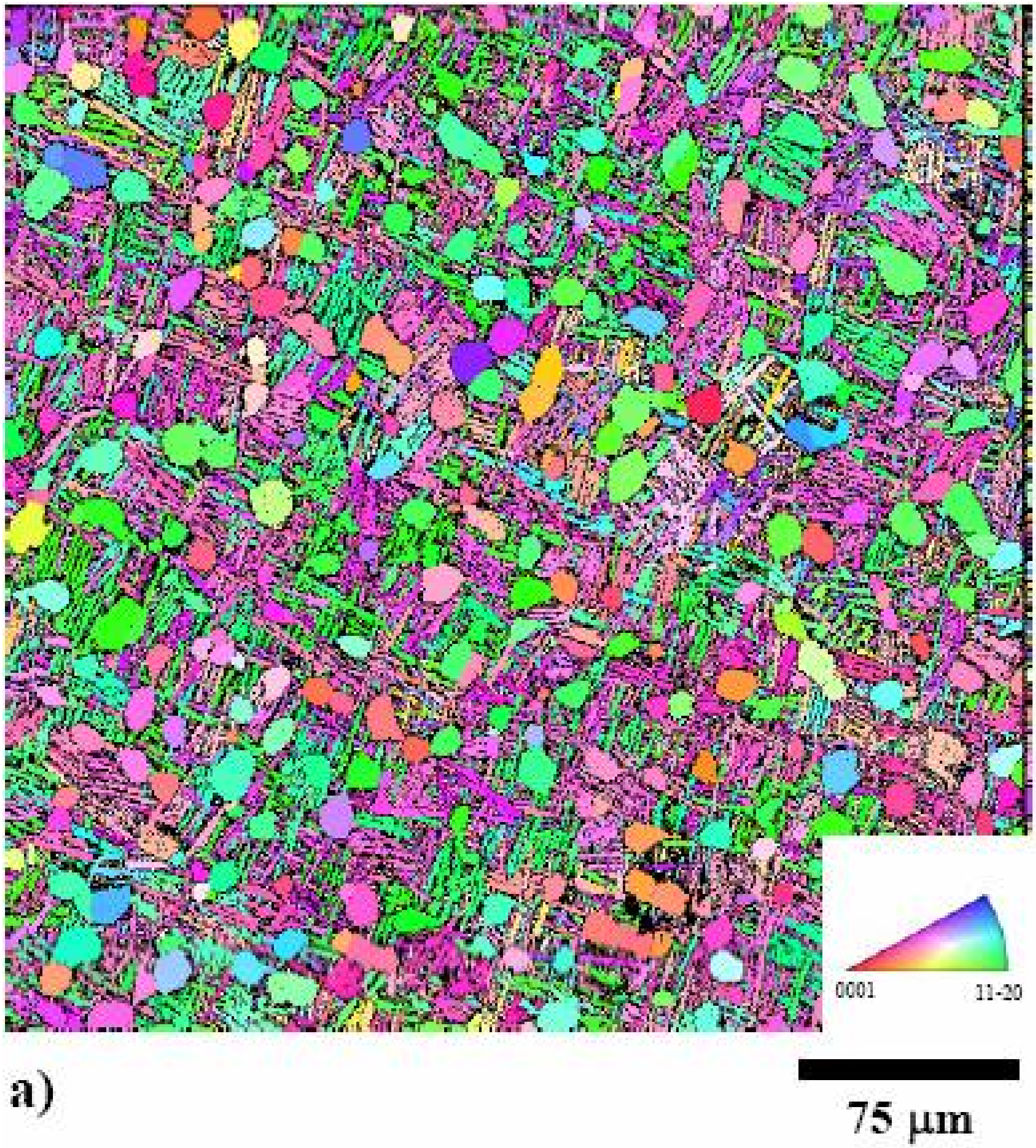


Figure 3c:



a)

Figure 4a:

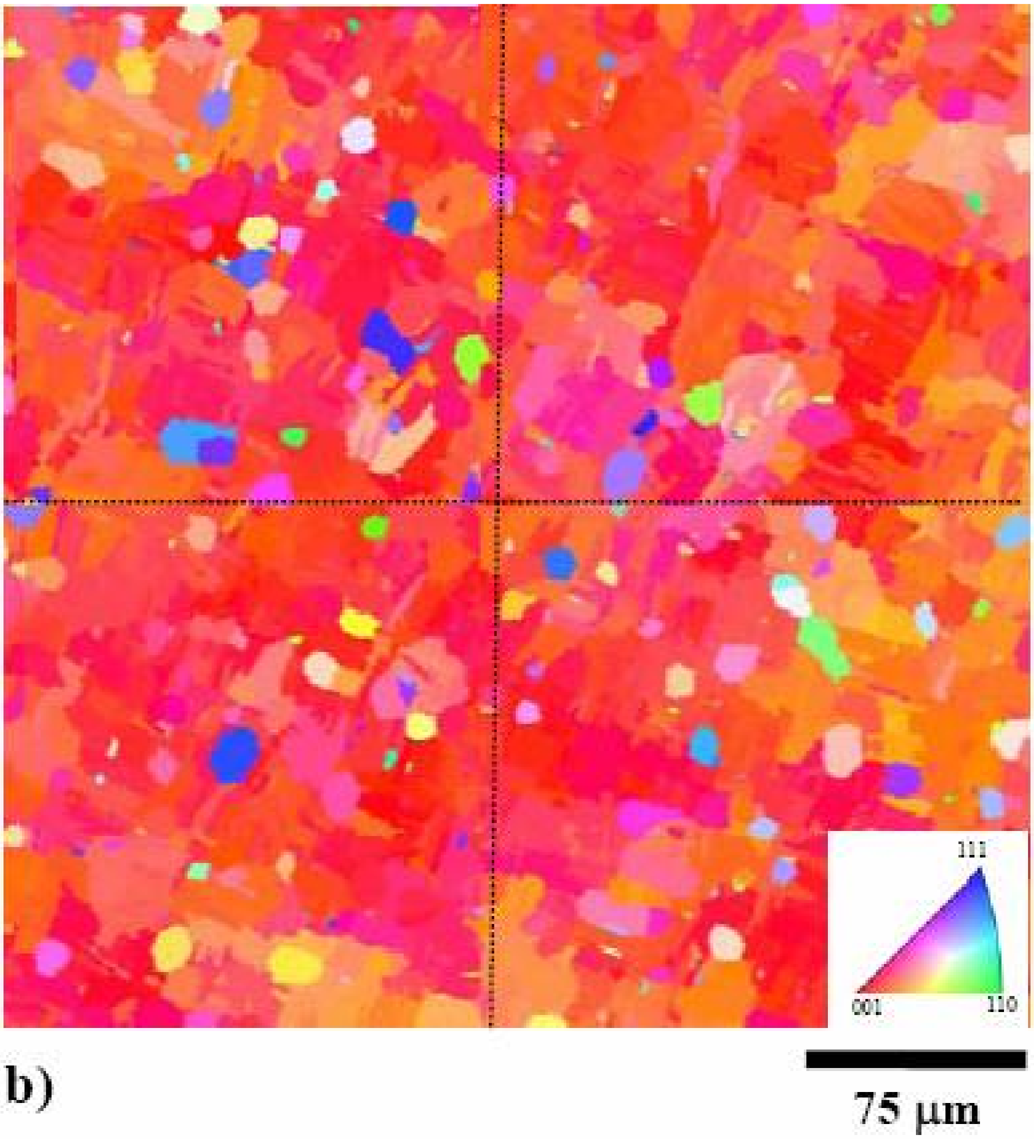


Figure 4b: